Antiproton Accumulation Status and Prospects

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Luminosity

- The major luminosity limitations are
  - The number of antiprotons (BN_{pbar})
  - The proton beam brightness (N_p/ε_p)
    - Beam-Beam effects
  - Antiproton emittance
  - F<1

$$L = \frac{3\gamma f_o}{\beta^*} BN_{\bar{p}} \frac{N_p}{\varepsilon_p} \frac{F\left(\beta^*, \theta_{x,y}, \sigma^L_{p,\bar{p}}, \varepsilon_{p,\bar{p}}\right)}{\left(1 + {}^{\varepsilon_{\bar{p}}}\!/\!_{\varepsilon_p}\right)}$$

- Antiproton Burn Rate
  - $n_c = 2$
  - $\sigma_a = 70$ mb
  - $L = 3.0\times10^{32}$ cm^{-2}-sec^{-1}
  - $\Phi = 15\times10^{10}$ hr^{-1}

$$\Phi^{(min)}_{\bar{p}} = n_c \sigma_a L$$

Stacking Rate

$$\Phi = \frac{N_p P}{T_{rep}}$$

- N_p is the number of protons on target
  - Slip Stacking
- P is the production ratio of the number of antiprotons produced to N_p
  - Typically about $15\text{-}20\times10^{-6}$
  - Mostly a function of the collection aperture
- T_{rep} is the cycle time
  - Mostly a function of the cooling rate

Studies, Studies, Studies

- Originally planned to dedicate 14 days of Pbar studies during low luminosity running
- First Tevatron Failure (B11 Separator)
  - Tue Nov 22 to Thu Dec 15
  - 23 days of dedicated studies
- Second Tevatron Failure (A44 vacuum)
  - Sun Jan 15 to Thu Jan 26
  - 12 days of dedicated studies
- Accumulator Aperture Work
  - Done during low luminosity running
  - Wed Feb 15 to Fri Feb 17
  - 3 days of dedicated studies

December Antiproton Study Period Statistics

Length of Time:	**Tue Nov 22 to Thu Dec 15**
Number of Elog shift pages:	**72**
Number of Recorded Debuncher Orbits:	**857**
Number of Recorded AP2 Orbits:	**775**
Number of Commissioned items:	**12**
Number of Major Accomplishments:	**$6+\frac{1}{2}+\frac{1}{2}$**
Number of Confusions (at the time):	∞
Number of Other Things Done:	**8+1**
Number of "Next Times" Known Items:	**$7\frac{1}{2}$**

December Antiproton Study Period

- Instrumentation Commissioned
  - Debuncher Reverse Proton Turn-By-Turn system
  - Debuncher Reverse Proton partial turn extraction up AP2
  - Debuncher Component Centering
  - Debuncher Orbit-Quad offset
  - AP2 Orbit-Quad offset
  - AP2 Beam Line Correction
  - One-Shot TLG for getting Debuncher beam
  - Admittance measurement from data-logger
  - "Deb Heat Rev p's to AP2" aggregate
  - AP2-Debuncher Injection region setup
  - Auto-tune 120 GeV orbit of P1-P2-AP1
- Scheduled Studies Accomplishments
  - Lattice measurements for Debuncher and AP2
  - Determine Debuncher Orbit/BPM-Quad offsets
  - Corrected Debuncher Vertical Orbit to Quad Centers
  - Centered Debuncher Components about orbit
  - Determine AP2 Orbit/BPM-Quad offsets
  - Set Orbit, Stands and Settings for AP2-Debuncher Injection Region
  - Corrected AP2 Orbit to near Quad Centers
  - Installed AP2 lattice that matches to current Debuncher Lattice

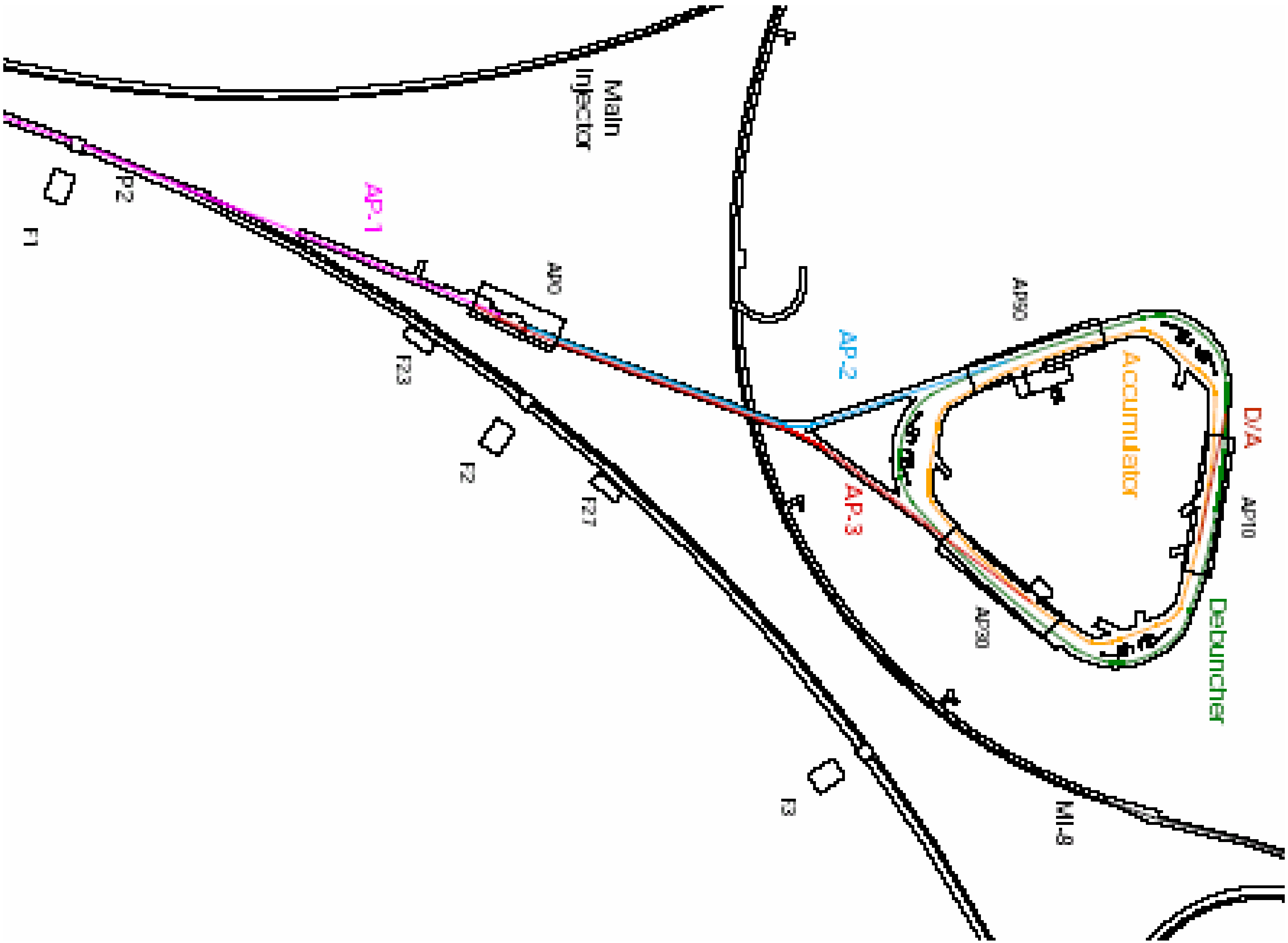
January Antiproton Study Period

- Quad Steering of the AP1 line
  - Not finished
- Alignment of the Debuncher horizontal orbit and moveable devices.
  - Did not do arcs
  - Need to Energy align the AP2-Debuncher-Accumualtor
  - Horizontal Aperture up to 35π-mm-mrad!!!
- Installation and commissioning of Debuncher lattice modifications
  - First round done
  - Vertical aperture up to 34π-mm-mrad
- Removal of the Debuncher Schottkies
  - Completed
- Obstruction search of the AP2 line.
  - Completed – none found
- Installation of 4 additional AP2 trims
  - Two trims installed
  - Two trims staged
- D/A Beam based alignment
  - Completed to the Q3-Q6 straight section
- Accumulator orbit and aperture optimization
  - Backed out of orbit changes
    - Need to update quad centering software
    - Need to de-bug running wave software
  - Will only complete moveable devices
  - Quadrupole Pickup found to aperture restriction

Major Focus of Studies - Beam Based Alignment

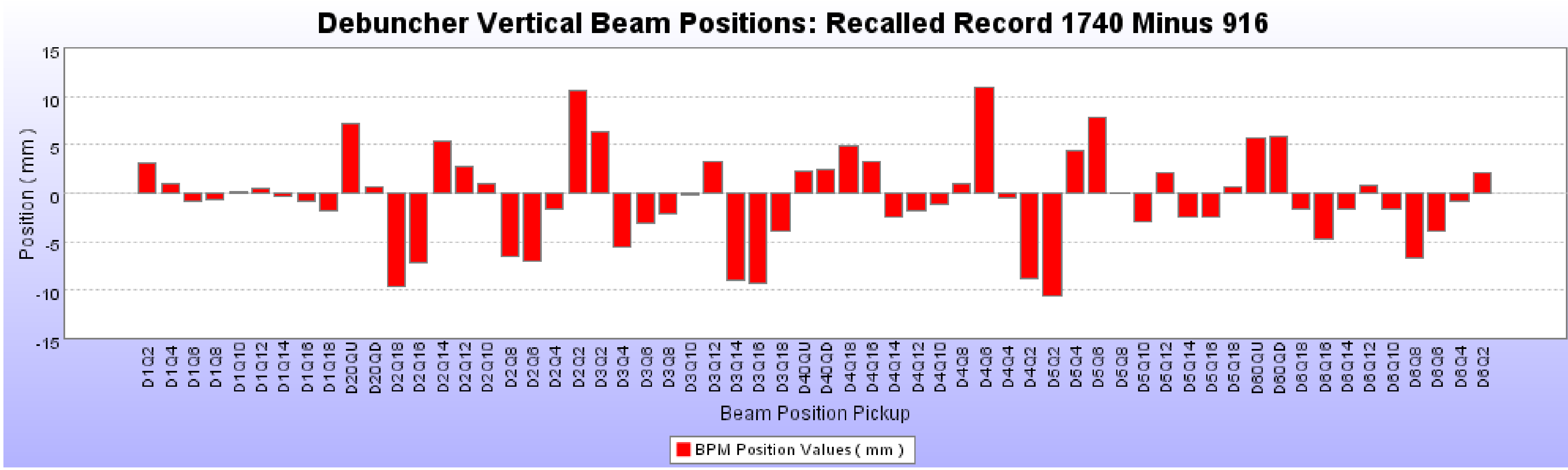
- For maximum aperture, we would like the beam to go through the center of the quadrupoles
- You cannot trust the absolute position of beam position monitors.
- If the beam goes off center through a quadrupole, it gets a kick. The kick is proportional to
  - strength of the quad
  - the offset of the transverse beam position with respect to the center of the quad.
- To measure how far off center the beam is in the quad
  - Measure the beam trajectory downstream of the quad with BPMs
  - Change the Quad current (strength)
  - Measure the difference in beam position
    - If the beam goes though the center of the quad, the trajectories will be the same
  - Change the position of the beam through the quad with an upstream trim magnet until the quad does not steer the beam.

AP2 Line and the Debuncher

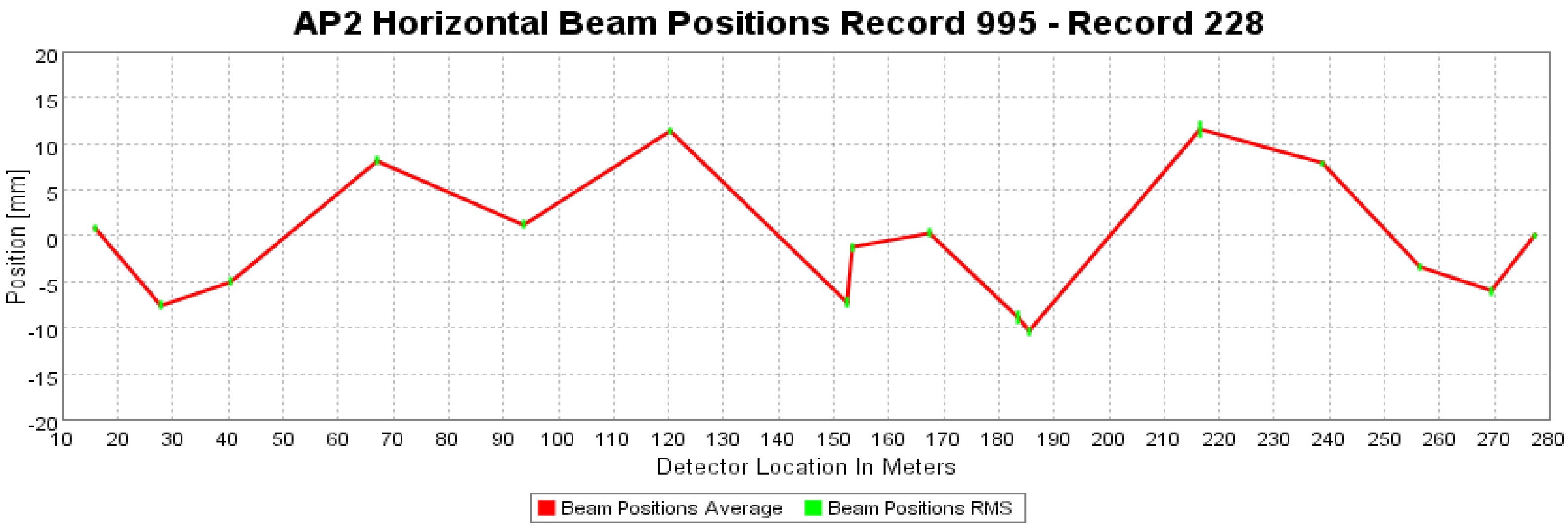


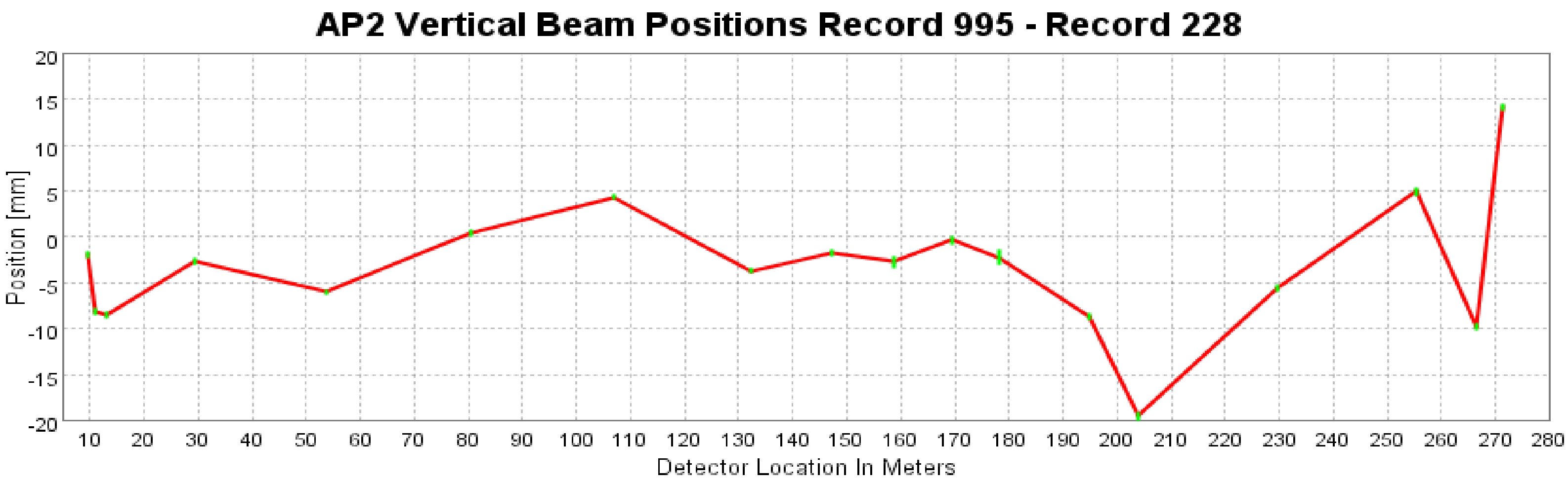
Change in Debuncher Vertical Orbit

- Determined Orbit-Quad center offsets
- Steered to center of quads
- Center components about orbit using motorized stands

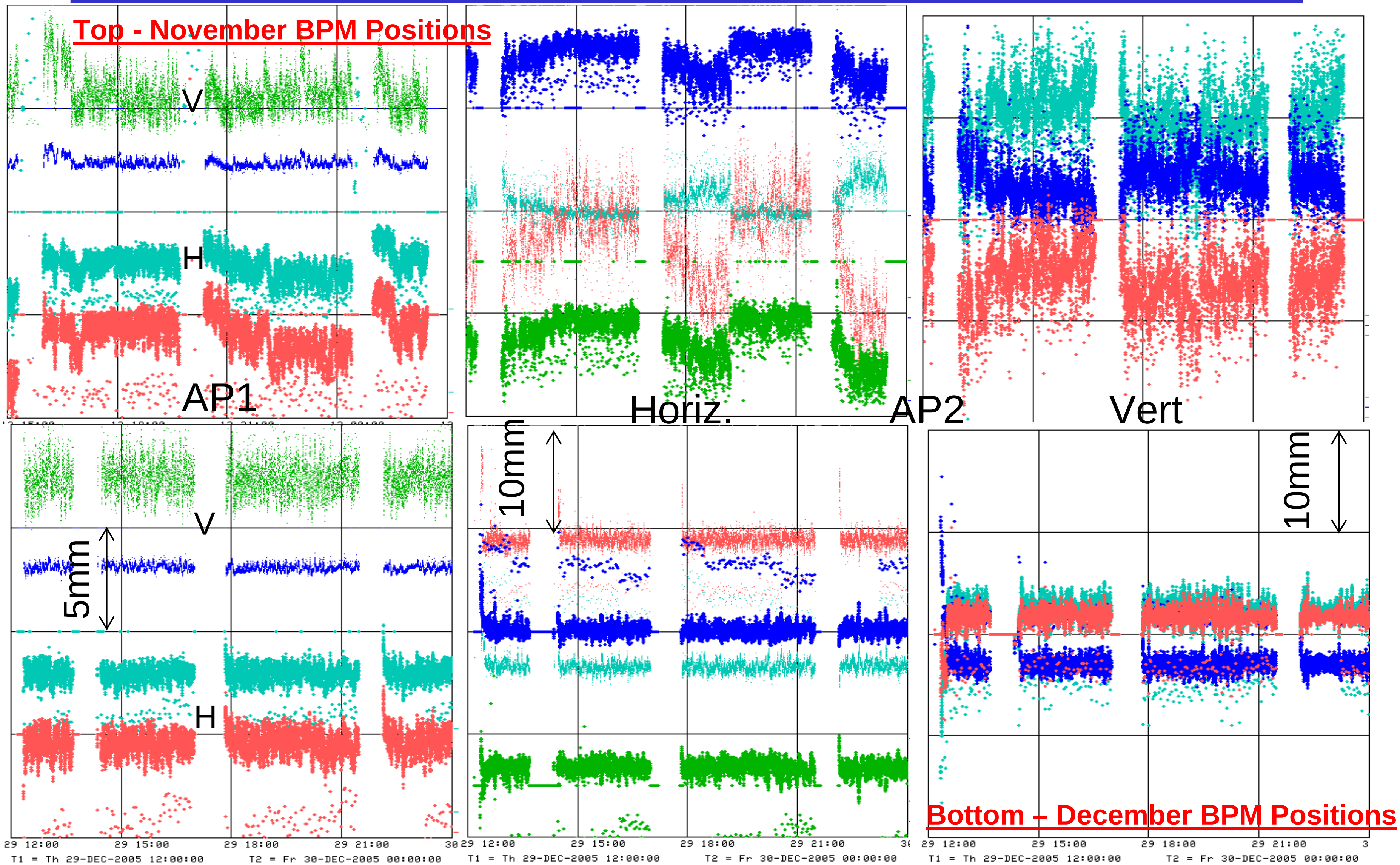


Change in AP2 Stacking Orbit





Primary and Secondary Beamline Auto-Correction (Oscillation Overthruster)

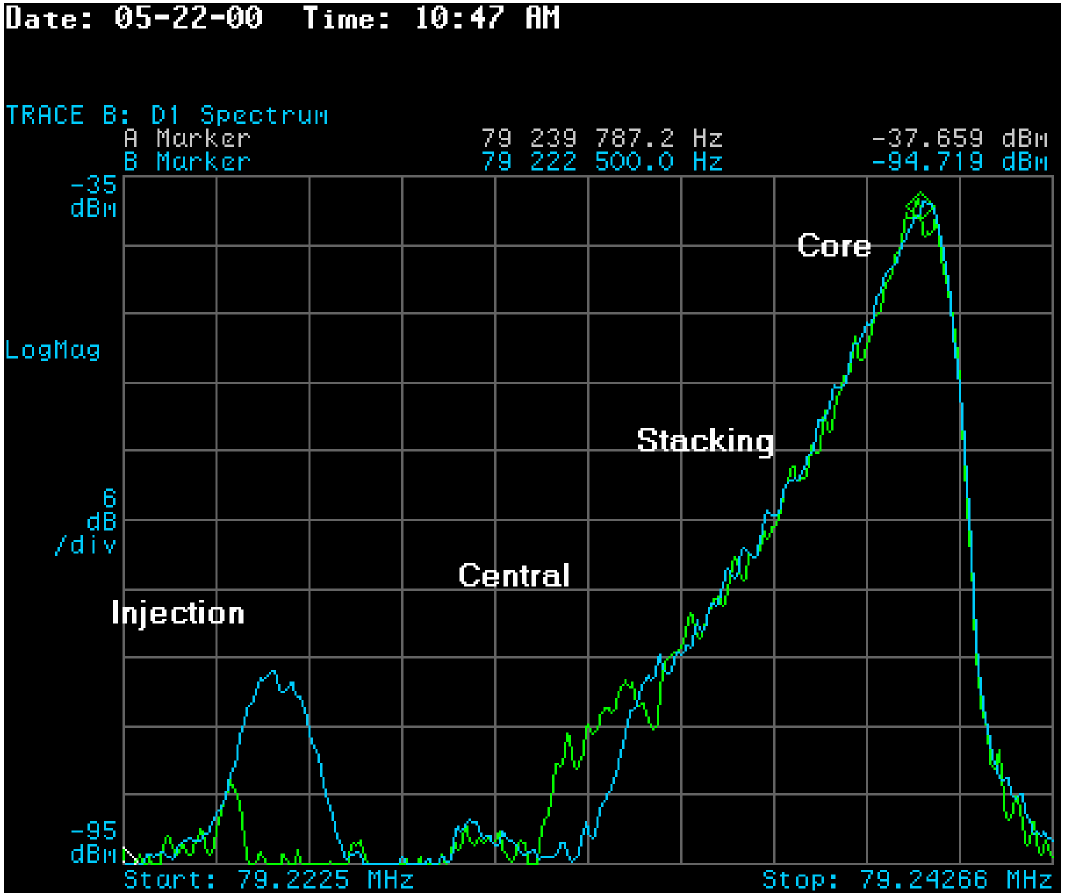


Returning to Stacking After the Studies

- Production into the Debuncher was good
- Overall production was a function of the amount of beam on target.
- Possible explanations
  - Spot size on target vs proton intensity
  - Bunch length on target vs proton intensity
  - Debuncher transverse cooling
    - Far away from optimum gain
    - Not tripping TWT's
  - Accumulator Stacktail Flux
- Measure production at various places along the chain as a function of intensity on target
  - All the beam making it into the Accumulator
  - Accumulator Stacktail cooling system choking

Antiproton Stacking - Stacktail System

- Beam is injected onto the Injection Orbit
- Beam is
  - Bunched with RF
  - Moved with RF to the Stacking Orbit
  - Debunched on Stacking orbit
- Stacktail pushes and compresses beam to the Core orbit
- Core Momentum system gathers beam from the Stacktail
- Accumulator Transverse Core Cooling system cools the beam transversely in the Stacktail and Core



Antiproton Stacking - Stacktail System

- The time evolution of the antiproton phase space during cooling is best described by the Fokker-Plank Equation

$$\frac{\partial\psi}{\partial t} = -\frac{\partial\phi}{\partial E}$$

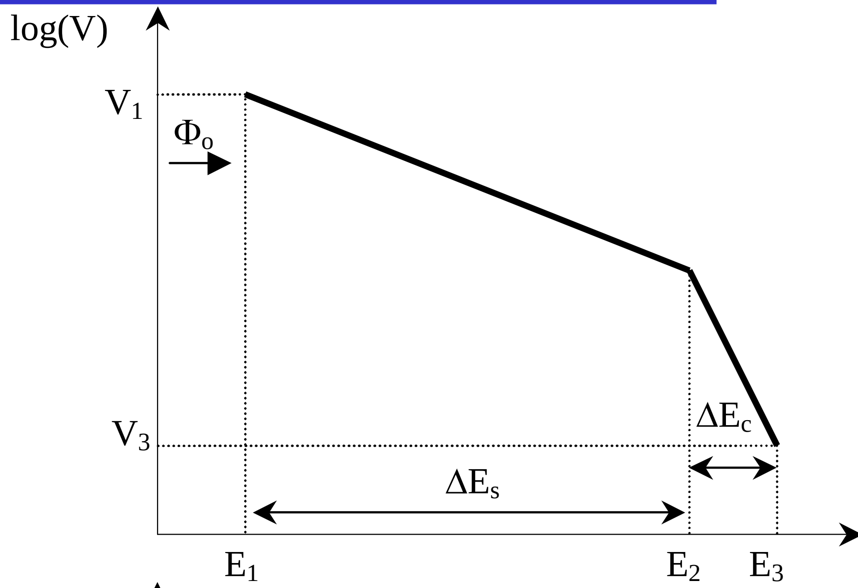
$$\phi_c = \frac{\Delta E_c}{T_o}\psi = eV_o f_o \psi \sum_n \mathrm{Re}\{G_n(E)\}$$

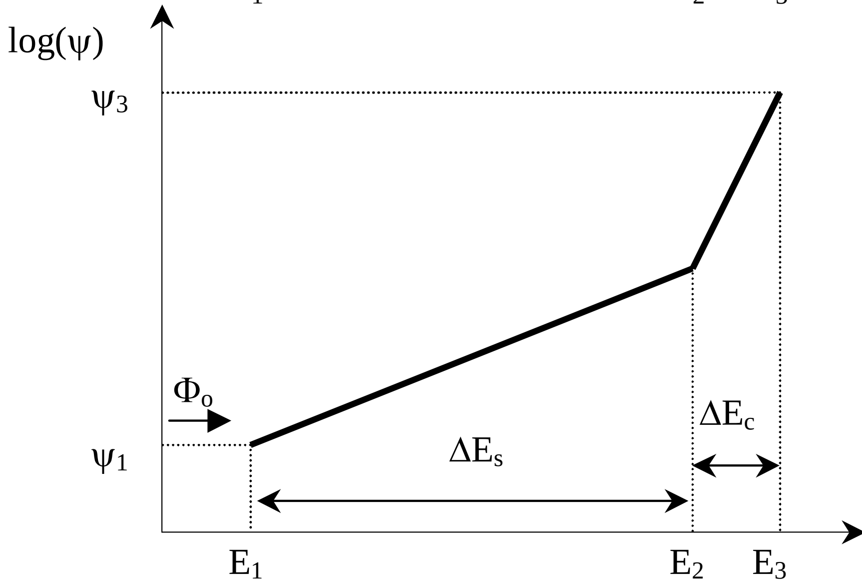
$$\phi_h = \frac{1}{2}\frac{\Delta E_h{}^2}{T_o}\frac{\partial\psi}{\partial E} = \frac{1}{4}(eV_o f_o)^2 \frac{E_o}{\eta f_o}\psi\frac{\partial\psi}{\partial E}\sum_n |G_n(E)|^2$$

- Optimum profile that maximizes $d\psi/dE$ for a constant stacking rate is exponential

$$G_n(E) = g_o e^{-E/E_d} \qquad \psi(E) = \psi_o e^{E/E_d}$$

$$\psi_o = \frac{N_T P_D}{\Delta E_{bD}} \qquad \boxed{\phi_m = \eta f_o \frac{E_d}{E_o}\frac{\left(W/f_o\right)^2}{\ln\left(f_{max}/f_{min}\right)}}$$





Antiproton Stacking - Stacktail System

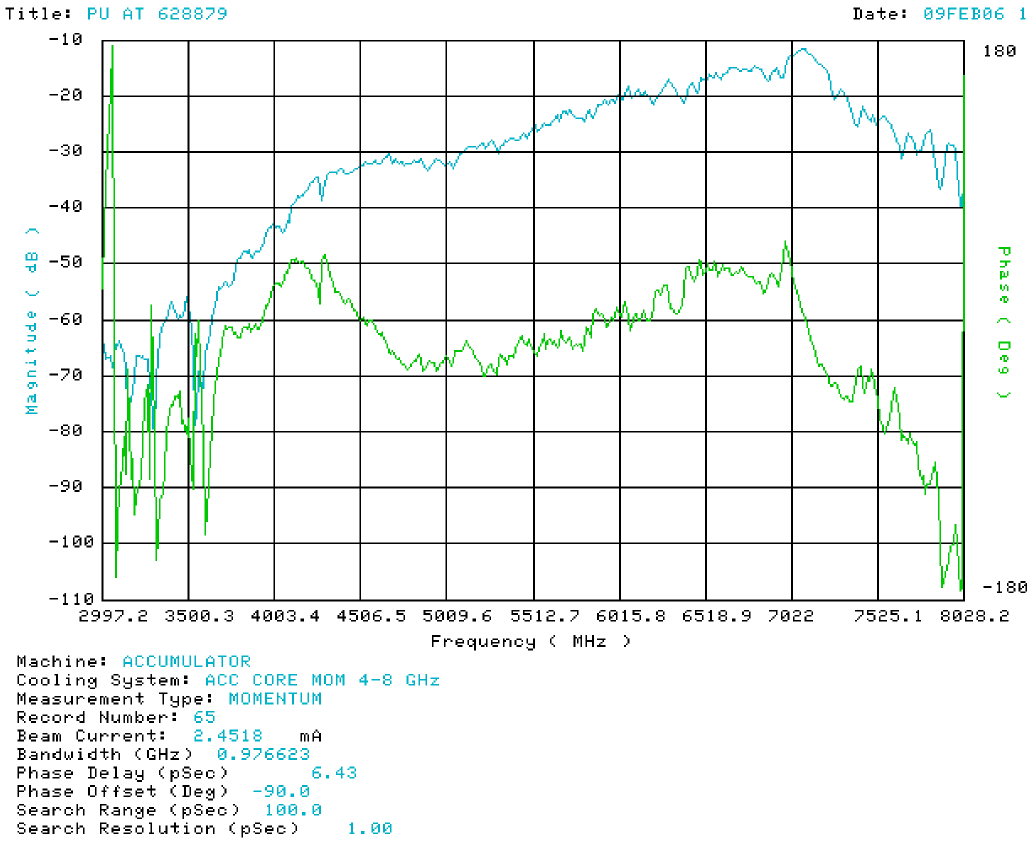
- The measured Accumulator 2-4 GHz Stacktail system can support a flux of 30mA/hr.
- The currently used 2-4 GHz core momentum system is the same frequency as the Stacktail system
  - At a flux of 15mA/hr, the core 2-4 GHz system can support a exponential gain slope that is a factor of two larger than the gain slope of the Stacktail.
  - As the number of particles in the core increases, the factor of 2 gain slope is exceeded and the core pushes back on the Stacktail and the flux must be reduced.
- For large fluxes into the Stacktail, the 2-4 GHz core momentum system cannot support a core.

Antiproton Stacking – Stacktail System and the Core 4-8 GHz System

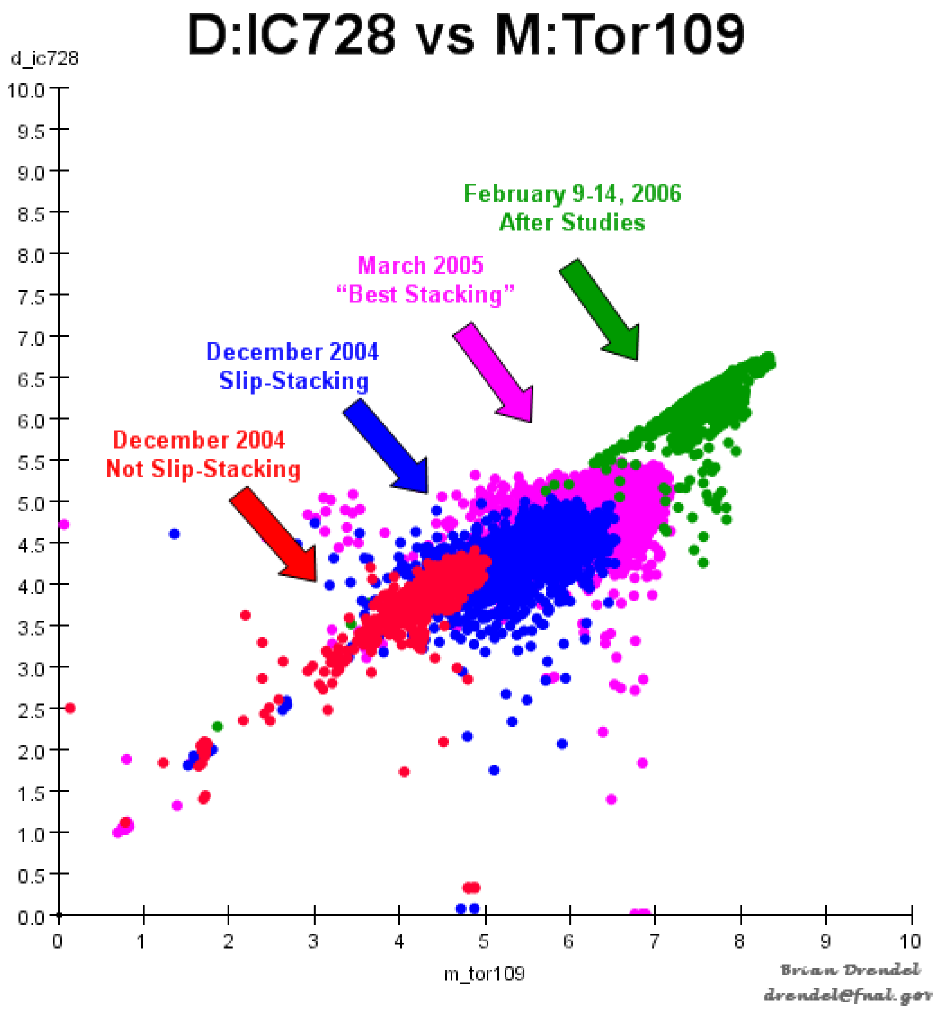
- To support a core at high flux, the 4-8 GHz core momentum system must be used.
- Because the 4-8 GHz core system runs at twice the frequency, the electrodes are ½ the size so the system has a factor of two smaller momentum reach.
- Moving the core closer to Stacktail to accommodate the smaller reach resulted in system instabilities at moderate stacks.
- We now :
  - Use the 2-4 GHz core momentum system to augment the hand-off between the Stacktail and the 4-8 GHz core momentum system
  - Run the 4-8 GHz core momentum system at MUCH larger gain.
  - Run the Stacktail during deposition debunching to pre-form the distribution to match the Stacktail profile

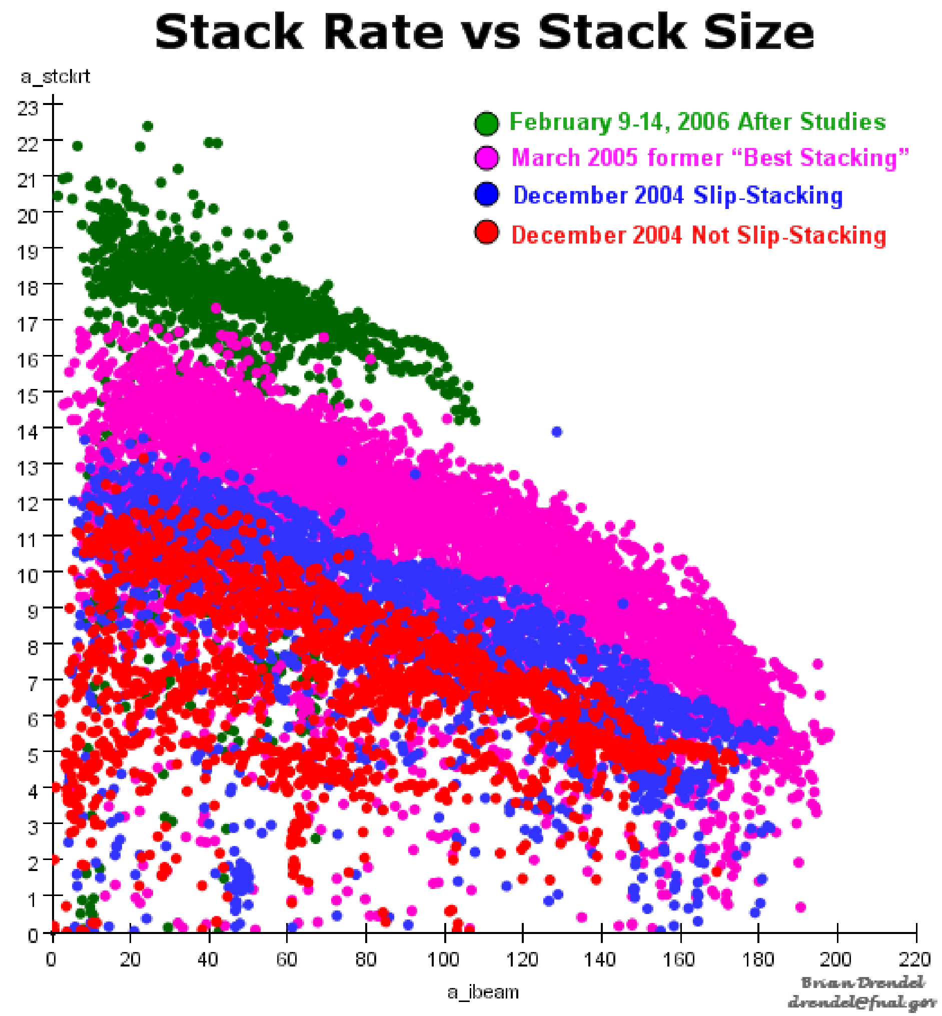
Core 4-8 GHz Momentum Cooling System bandwidth

- 1 GHz of bandwidth at 7 GHz is ~3x more powerful than 1 GHz of bandwidth at 2.5 GHz
- With simple redesign of the system equalizers, the 4-8 GHz system will be 5.7x more powerful than the 2-4 GHz system



Stacking Performance





Antiproton Parameters

			Antiproton Parameters				
Phase	1	2	3	4	5	6	
Zero Stack Stacking Rate	13.0	16.0	18.9	30.2	30.2	30.2	$x10^{10}$/hour
	13.0	16.0	16.6	25.2	25.2	25.2	
	13.0	16.0	16.6	20.2	20.2	20.2	
	13.0	16.0	16.0	16.0	16.0	16.0	
Average Stacking Rate	6.3	7.4	9.6	21.7	21.7	21.7	$x10^{10}$/hour
	6.3	7.4	8.5	14.8	17.4	17.4	
	6.3	7.4	8.5	11.3	11.3	13.3	
	6.3	7.4	8.3	8.3	8.3	9.7	
Stack Size transferred	158.2	163.8	211.5	476.5	476.5	476.5	$x10^{10}$
	158.2	163.8	187.9	324.7	382.5	382.5	
	158.2	163.8	187.9	248.6	248.6	293.5	
	158.2	163.8	181.5	181.5	181.5	214.5	
Stack to Low Beta	117.1	124.5	169.2	381.2	381.2	381.2	$x10^{10}$
	117.1	124.5	144.7	253.3	298.3	298.3	
	117.1	124.5	144.7	191.4	191.4	226.0	
	117.1	124.5	138.0	138.0	138.0	163.0	
Pbar Production	16.0	15.0	16.0	21.0	21.0	21.0	$x10^{-6}$
	16.0	15.0	15.0	17.5	17.5	17.5	
	16.0	15.0	15.0	16.0	16.0	16.0	
	16.0	15.0	15.0	15.0	15.0	15.0	
	FY04 Plan	**Slip Stacking**	**Recycler Ecool**	**Stacktail**	**Helix**	**Reliability**	

Future Pbar Work

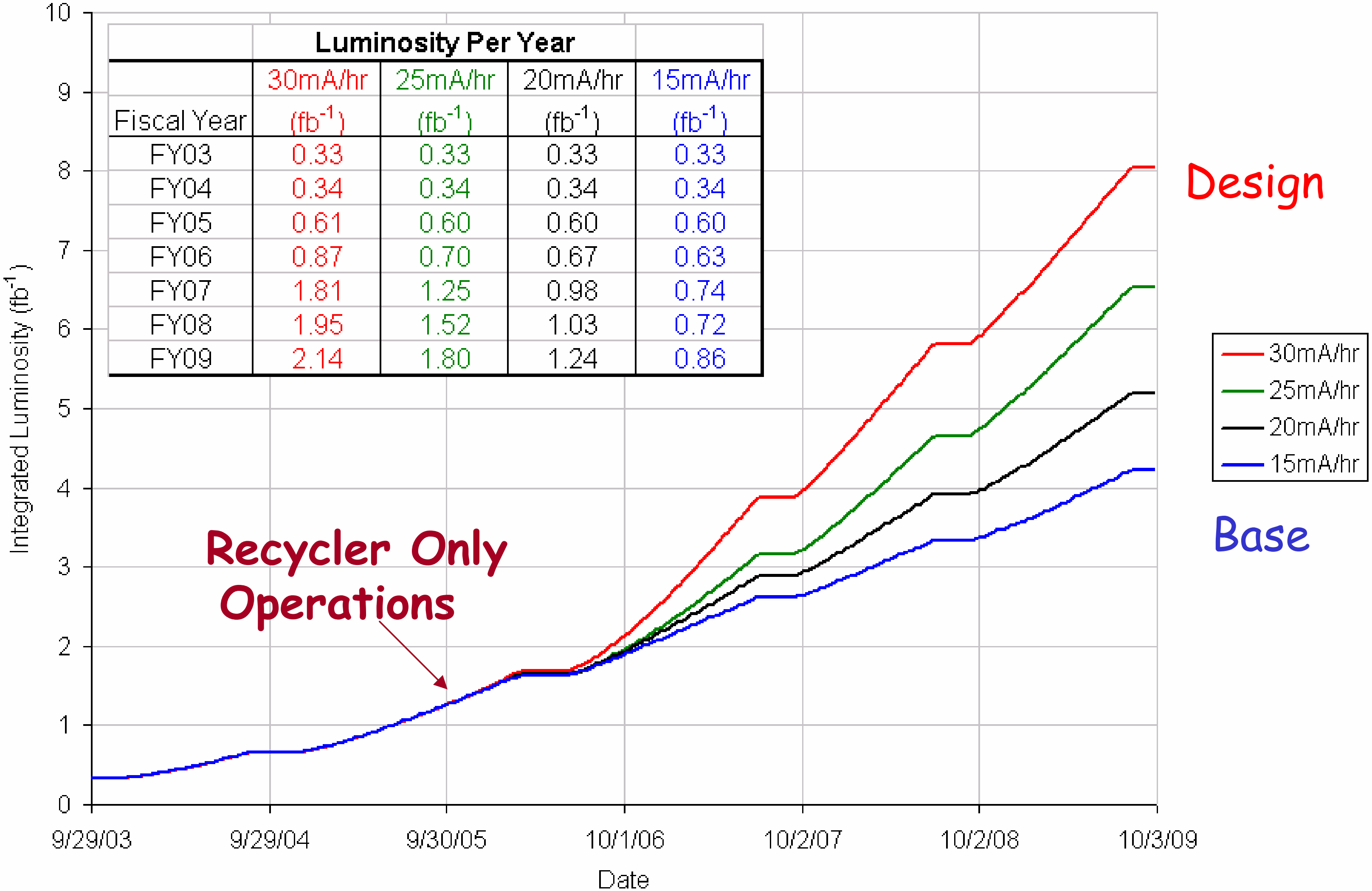
- Lithium Lens (0 – 25%)
  - Lens Gradient from 760T/m to 1000 T/m
- Slip Stacking (7%)
  - Currently at 7.5×10^{12} on average
  - Design 8.0×10^{12} on average
- AP2 Line (5-30%)
  - Lens Steering
  - AP2 Steer to apertures
  - AP2 Lattice
- Debuncher Aperture (13%)
  - Currently at 30-32um
  - Design to 35um
- DRF1 Voltage (5%)
  - Currently running on old tubes at 4.0 MEV
  - Need to be a t 5.3 MeV
- Accumulator & D/A Aperture (20%)
  - Currently at 2.4 sec
  - Design to 2.0 sec
- Stacktail Efficiency
  - Can improve core 4-8 GHz bandwidth by a factor of 2
- Timeline Effects
  - SY120 eats 7% of the timeline

Prospects

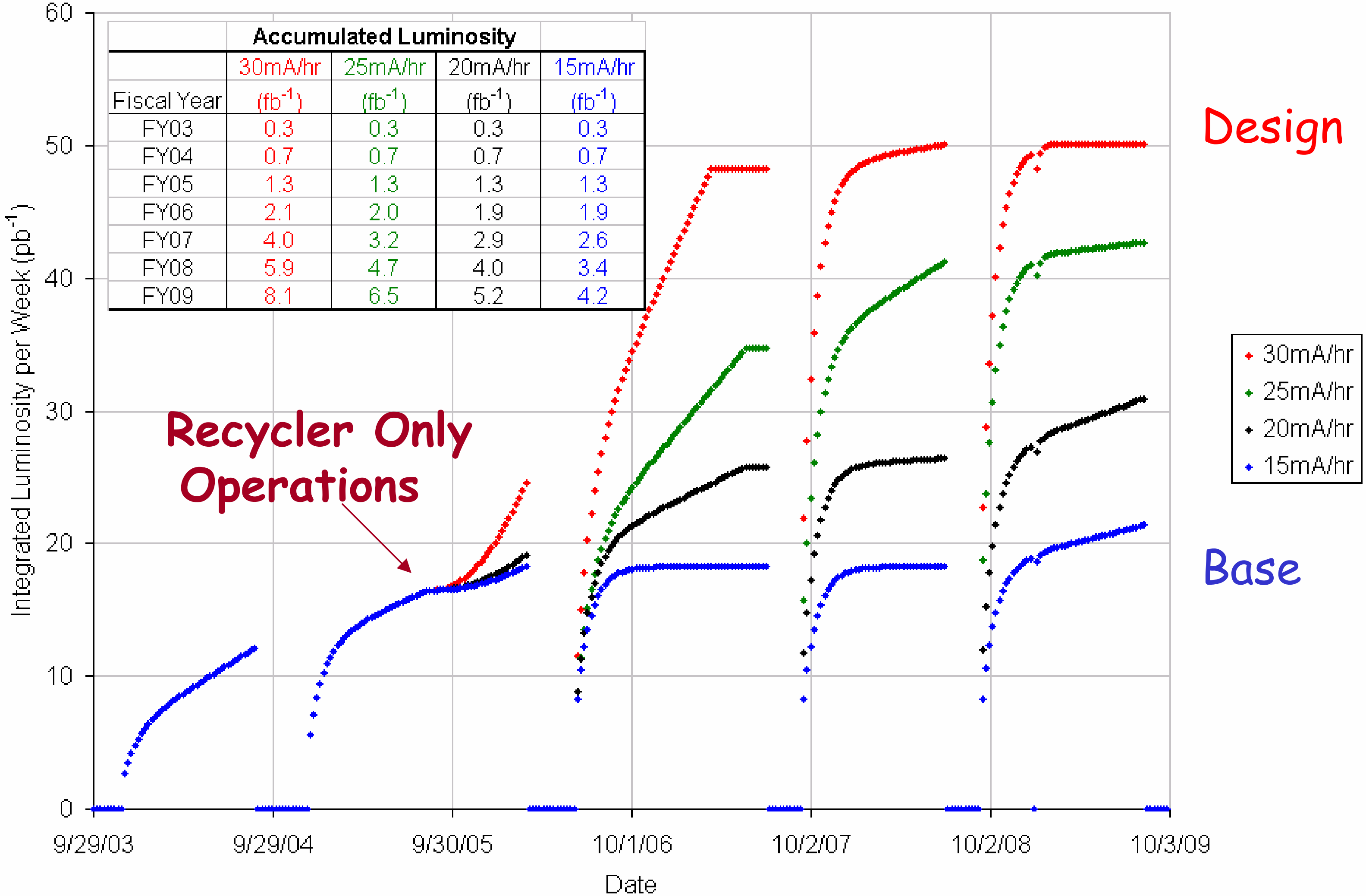
- With the progress of the past studies, it is very likely that we will achieve 30mA/hr within the next year (Feb 07).
  - Using the conservative end of the range will give a 60% increase in stacking (32mA/hr).
  - Using the upper end of the range will give a 180% increase in stacking (55mA/hr – Run 2 Upgrade "stretch" goal)
- Goals
  - Achieve 25 mA/hr by September 2006
    - AP2 Line (5-30%)
    - Accumulator & D/A Aperture (20%)
  - Decide on the Stacktail Upgrade
    - To take advantage of the stacktail upgrade,
      - a large pbar flux is needed (>30mA/hr)
      - rapid transfers to the Recycler to keep the accumulator core small.
    - The stacktail upgrade will remove our ability to go to even modest stack sizes.

Integrated Luminosity

	Luminosity Per Year			
Fiscal Year	30mA/hr (fb^{-1})	25mA/hr (fb^{-1})	20mA/hr (fb^{-1})	15mA/hr (fb^{-1})
FY03	0.33	0.33	0.33	0.33
FY04	0.34	0.34	0.34	0.34
FY05	0.61	0.60	0.60	0.60
FY06	0.87	0.70	0.67	0.63
FY07	1.81	1.25	0.98	0.74
FY08	1.95	1.52	1.03	0.72
FY09	2.14	1.80	1.24	0.86



Weekly Luminosity Projection



	Accumulated Luminosity			
	30mA/hr	25mA/hr	20mA/hr	15mA/hr
Fiscal Year	(fb^{-1})	(fb^{-1})	(fb^{-1})	(fb^{-1})
FY03	0.3	0.3	0.3	0.3
FY04	0.7	0.7	0.7	0.7
FY05	1.3	1.3	1.3	1.3
FY06	2.1	2.0	1.9	1.9
FY07	4.0	3.2	2.9	2.6
FY08	5.9	4.7	4.0	3.4
FY09	8.1	6.5	5.2	4.2

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Peak Luminosity Projection